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ASSESSING THE LEVEL OF IMPLEMENTATION OF LEAN CONSTRUCTION: AN AUDIT PROTOCOL

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ABSTRACT

The implementation of lean construction still faces barriers mainly in its initial stages. It occurs, in part, due to the lack of evaluation tools that enable the acknowledgment of its true value for the companies.

Thus, this paper aims to present an audit protocol to evaluate the level of lean implementation. Developed under Design Science methodological background, the audit protocol was proposed based on literature. To evaluate the applicability, the pilot protocol was implemented and tested into 4 construction companies from the city of Fortaleza, northeast of Brazil. The pilot revealed improvements to improve the protocol. Then, the improved protocol was evaluated and validated by 5 lean construction experts, resulting in the final protocol which was composed by 4 dimensions, 35 categories, 136 items and 223 examples of verifying evidences.

Was verified that the protocol allows more than identify the lean implementation level, but enables a lean journey if used as a guidebook to lean implementation. The proposed audit protocol can be also used to cyclic evaluation that enables the improvements of the identified gaps, through a deep comprehension of the critical factors that can prevent the success of lean construction in the companies.

KEYWORDS

Lean construction, improvement, evaluation tool, implementing lean, integration.

INTRODUCTION

Implement lean is a great challenge for any company from any sector. This is evident in the literature, since the efforts of Womack *et al*. (1990) that results in a generalization of Toyota principles, theoretically applicable in any company (Womack and Jones, 1996). Despite of this efforts, there is no consensus of this generalization, principally if

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considering the construction industry (Koskela, 2004). In construction industry, the application of Toyota principles are based in Koskela (1992), called as Lean Construction by founders of International Group for Lean Construction in 1993 (Koskela, 2004).

Since Koskela (1992), many researchers report the success and pitfalls of lean construction implementation (Ballard, 1993; Alarcón *et al.*, 2005; Sarhan and Fox, 2013; Zanotti, Maranhão and Aly, 2017), indicating that the lean implementation question remains open. This question, can occur due to a poor vision of lean as a tool box (Atkinson, 2010) and because of the lack of evaluation tools that allows the acknowledgement of its true value for the companies (Li *et al.*, 2015a; Cândido and Barros Neto, 2017).

Thus, an alternative to help companies to widespread implement lean in industry is evaluate implementation through audit protocol (see Karlsson and Ahlström (1996), Åhlström (1998), Soriano-Meier and Forrester (2002) and Bhasin (2011)). The use of tools to analyse lean implementation is an alternative for construction industry, as can be seen in previous IGLC proceedings as Diekmann et al. (2003), Hofacker et al. (2008), Valente et al. (2012), Etges et al. (2012, 2013), Nesensohn *et al*. (2014, 2015) and Li *et* al. (2015).

Although this apparent prolific literature, efforts to improve the lean implementation and its evaluation, remains a valuable initiative. Thus, this paper aims to present an audit protocol to evaluates the level of lean implementation. Developed under Design Science methodology background, the audit protocol was proposed based on literature.

The audit protocol to evaluates lean level of implementation was structured based on the 4P's (Liker, 2003): philosophy, process, people and partners and, finally, problem solving. This choice was taken due to the epistemological dispersion in the foundation of lean concepts in its different areas, as Krafcik (1988) seminal paper in the terminology of Lean Production System, Womack, Jones and Ross (1988) and later Womack and Jones (1996) used the terminology Lean Thinking and Koskela (1992) used Lean Construction. This dispersion can lead a misunderstood about of what is lean, as pointed by Koskela (2004). Finally, it is unanimous among the aforementioned authors that they are natural descendants of Toyota Production System (TPS), which justifies the choice of the TPS Pyramid proposed by Liker (2003) as framework of the audit protocol proposed.

EVALUATING LEAN CONSTRUCTION IMPLEMENTATION LEVEL

The implementation of lean construction in the construction industry generally presents strong barriers that can make it unfeasible, as it happens in the adhesion of other processes of organizational improvements. The adoption of lean construction demands investments and measurement of its benefits (Campos et al. 2012), which are frequently misunderstood and considered as shortcoming (Cândido and Barros Neto, 2017).

To correctly guide this process, the use of an efficient audit model in companies that use this philosophy of production management might/may contribute to operational efficiency of lean construction (Etges, Saurin and Bulhões, 2013). As an example in industry, Karlsson and Åhlström (1996), Soriano-Meier and Forrester (2002) and Bhasin (2011), proposes an evaluations to assess the Lean implementation and its benefits. In the

construction industry, some authors also tried to evaluate the lean construction implementation level as showed in the Table 1.

Table 1: Models to evaluating the level of lean construction implementation published at IGLC

Author	Dimensions	Maturity Level	Evaluation	Application/ Validation	Strengths	Weakness
Diekmann et al. (2003)	5	No	Organization	No	- Justify the importance of the evaluation categories based on literature	- There is no application or validation - The categories are evaluated superficially
Salem et al. (2006)	6	No	Construction Site/ Project	Yes, a unique case study	- Simplicity - Relates the expectations and the currently level of implementation of lean tools	-Limited number of lean practices - Unique case study
Hofacker et al. (2008)	6	12	Organization	No	- Simple and rapid to applicate	-Limited number of lean practices - There is no discussion about each category
Campos et al. (2012)	06	12 to lean and 5 for sustainability	Organization	Yes, tow applications	- Relates the level of lean implementation with sustainability	- There are no improvements in previously frameworks used to evaluates lean as well as sustainability
Valente et al. (2012)	7	No	Construction Site/ Project	Yes, four construction sites	- Enables a continuous improvement for lean practices - Assume the variation of level of leanness according the construction phase	- Developed for a specific company - There is no external validation Focused only production issues
Etges et al. (2012, 2013)	15	No	Organization	Yes, 18 experts and application in a unique case study	- Robust and extensive list of lean practices - Demands different source of evidence to evaluate lean practices	- Requires a lot of time-consuming to apply (4 hours)
Nesensohn et al. (2014, 2015)	11	5	Organization	No, validated through experts' interviews	- Robust and extensive list of lean practices - Demands different source of evidence to evaluating lean practices	- There is no external validation - There is no discussion about each category
Li et al. (2015)	6	No	construction site/project	Yes, 300 projects	- Extensive empirical data collection - Demands different source of evidence to evaluating lean practices	- Measuring only the results of lean and not its really usage - Limited number of lean issues

Based on this literature, the dimensions were compared between them as well as the evaluation items, from which the pilot protocol was proposed.

METHOD

This paper was developed under Design Science methodological background, based on Lukka (2003), Hevner et al. (2004) and Van Aken (2004). The research process is showed in Figure 1.

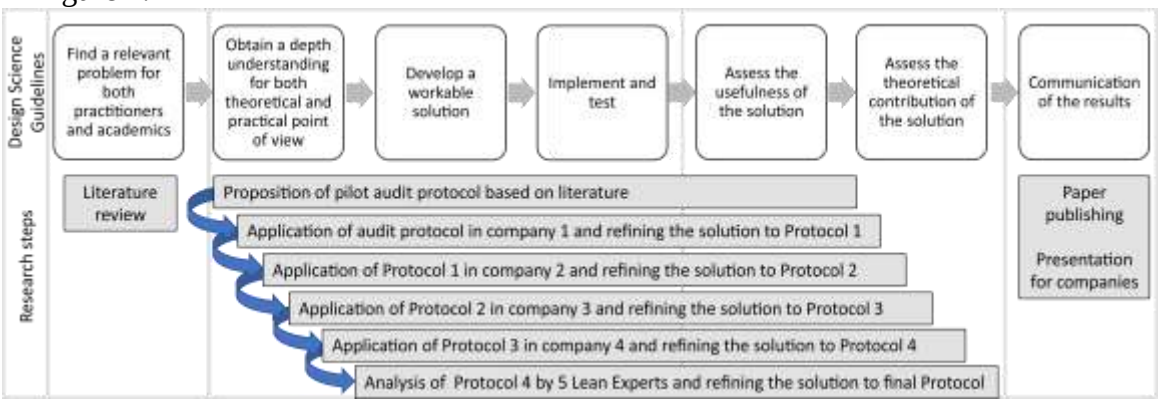

Figure 1 - Designed Research Process

Initially, a literature review was conducted focused in IGLC proceedings, from which five papers that proposes an evaluation of lean implementation was found. Through the exanimating of its references Salem et al. (2006) work was found and added into content analysis. Then, a pilot audit protocol was proposed based on literature and refined through four applications in four building companies from Fortaleza, city of Brazil. The main characteristics of the four companies are presented in Table 2.

Table 2: Building companies' characterization

Company	Market segmentation	Age	Time of lean application	Interviewed
A	Residential, corporate and industrial building	37 years	05 years	Planning Coordinator
B	Residential and corporate building	23 years	13 years	Planning Manager
C	Residential and corporate building	29 years	19 years	Technical Director
D	Residential and industrial building	40 years	13 years	Lean and Green Coordinator

In each of these cases were analysed the applicability and the understanding of the interviewees about the items of evaluation. Regardless of several types of evidence were requested and analysed, increasing understanding of how companies are fulfilling the items evaluated. Propositions of improvements for the audit protocol were performed, which increased the depth of understanding for both theoretical and practical point of view and the workable solution demanded by methodological background.

Finally, the interviewees analysed the usefulness of solution, they reached consensus about its useful. The main critic noticed by the interviewees was the high consumption of time for the audit process, about 2 hours. After the cycle of implementation, test and refining, the refined protocol was evaluated and validated by 5 lean construction experts (Table 3).

Table 3: Lean construction expert characterization

Expert	Formal Education/ High degree	Professional Experience	Level of LC knowledge*	Involvement with LC*
A	Bachelor's degree in civil engineering and business administration, PhD in civil engineering and post doctorate in construction and housing economy	41 years, currently is professor at State University of Ceará	10	7
B	Bachelor's degree in civil engineering and master's degree in industrial engineering	27 years, currently is Technical Director in a building company	8	8
C	Bachelor's degree in civil engineering and master's degree in industrial engineering	19 years, currently is Technical Director in a building company	8	10
D	Bachelor's degree in architecture and urbanism/ master's degree in civil engineering and master's degree in industrial engineering	10 years, currently is architect at Federal Institute of Ceará	8	8
E	Bachelor's and master's degree in civil engineering	08 years, currently is professor at Federal University of Ceará	8	10

Legend: * 0 to 10.

Each expert evaluated the dimensions, categories, evaluation items and the scale of points. They approved the audit structure and scoring, however they suggested a rearrangement of categories and new items. Moreover, there is no consensus about the importance among each principle of Toyota pyramid suggested by Liker (2003). Finally, there was wide consensus among the interviewees about the applicability of the audit protocol, as well as its reliability for measuring the lean implementation level.

PRESENTING THE AUDIT PROTOCOL TO EVALUATE THE LEVEL OF LEAN IMPLEMENTATION

An audit protocol can be analysed as a performance measurement tool. Thus, the audit protocol can be structured in two components (Cândido, Lima and Barros Neto, 2016): architectural and processual framework. The architectural framework of the final audit protocol was structured in three levels of aggregation (Yu *et al.*, 2007): dimensions (based on Toyota model), categories and evaluation items that need evidence in action. The processual framework was structured in three steps, based on Franco-Santos et al. (2007): (1) data collection and manipulation; (2) results communication and performance evaluation; (3) system review.

ARCHITECTURE OF AUDIT PROTOCOL

The characterization of audit protocol is presented in Table 4.

Table 4: Audit protocol characterization

Dimensions	Category	Evaluation items	Source of evidences
Philosophy	Lean Culture	05	10
	Lean Behavior	06	11
	Customer Focus	07	15

		Environment	04	07
		Waste management	06	12
		Wellbeing and safety work	05	08
Subtotal		**6**	**33**	**42**
Process	Flow	Work Flow	11	19
		Material	09	18
		People	03	05
		Equipment	03	05
	Tools	Quality control	05	09
		Autonomation	05	10
		Standardized Work	07	14
		5S	06	11
		Transparency	04	04
		Knowledge and Information Management	04	10
	Planning and Control	Design Planning and Control	06	10
		Production Planning and Control	06	11
		Cost Planning and Control	06	11
	Subtotal	**23**	**75**	**137**
People		Lean Leadership	05	09
		Learning and growth of internal clients	05	06
		Learning and growth for supply chain	06	08
Subtotal		**03**	**16**	**23**
Problem Solving		Problem identification	03	06
		Problem Solving	03	05
		Continuous improvement	06	10
Total		**03**	**12**	**21**
Dimensions: 04		**Categories: 35**	**items: 136**	**evidences: 223**

Due to the size of this paper, in following, we present an example of evaluation item in Table 5.

Table 5: Example of evaluation items to the dimension 'Philosophy' in the category "Lean Culture "

Item	Question	Evidences	Reference
01	Does lean construction cover all sectors of the company from planning to execution of the project?	* Interview senior management to see if the implementation of lean construction covers all sectors of the company; * Find out if the company has expert advice to support the implementation of lean construction.	Nesensohn et al. (2015)
( ) Yes.Tot ( ) Yes.Part ( ) No ( ) N.A.		**What are the evidences that prove the attendance of the question?**	
02	Is lean construction being propagate as a strategic vision of the business, and are all constantly striving toward this direction?	* Interview top managers to see if the implementation of lean construction is part of the strategic planning of the company; * Interview the senior management to find out if is included in the financial investment plans of the company, funds intended for the implementation of lean construction.	Hofacker et al. (2008), Carvalho (2008)
( ) Yes.Tot ( ) Yes.Part ( ) No ( ) N.A.		**What are the evidences that prove the attendance of the question?**	

The audit protocol is presented in full in Comelli (2018), a M.Sc. Dissertation, and as a supplementary document of this paper available at <http://bit.ly/2ILus0H>.

PROCESS OF AUDIT PROTOCOL

As previously stated, the process of auditing was structured in three steps. The data collection and manipulation are conducted through interviews sections, documents and observations. Thereinafter, the score of evaluation is assigned according with Table 6.

Table : 6 Scores of evaluations item

Evaluation item	Interpretation	Scores
Fully implemented	The item is systematically evidenced in action	1.0
Partially implemented	The item is inconsistent evidenced in action	0.5
Not implemented	The item is hardly evidenced in action	0.0
Not applicable	There is no applicability in the evaluation	Not computed

It should be noticed the difference between not implemented (zero) and not applicable (not computed). The Lean Construction implementation level in the particular dimension (LILD) is calculated as a percentage of scores obtained relative to maximum for each category. Thus, when an item is assigned as 'not implemented' he is not counted for the percentage. This option was made due to the difference among them (Table 4). For example, there is 33 evaluation items in Philosophy dimension and and 77 in Process dimension. Consequently, there is more possibilities to score in process dimension than Philosophy.

The results communication is initially exhibited through a radar chart, in which each axis corresponds to a dimension analysed, and a list of items from 'Partially implemented' to 'Not implemented' is presented, clarifying the opportunities of improvements. In Then, the LILD is calculated.

Based on the LILD achieved is provided a profile for the company (inspired in Succar (2009), from which is possible to classify into 4 categories as showed on Figure 2.

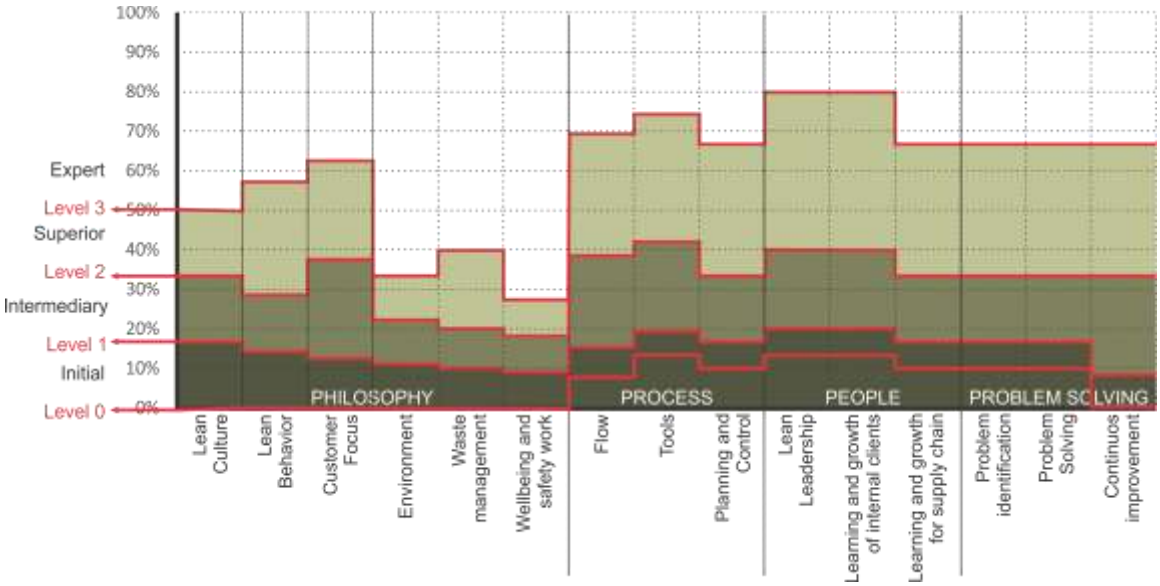

Figure 2: The final classification

Propose a profile, instead of an aggregate result, in the view of the authors it is more suitable because of the lack of agreement about the relative importance of each principle

of TPS Pyramid. In a second reflection, it is hard to think in terms of practices hierarchization in different project contexts, which led the proposition of classification to be based on the sum of efforts to implement lean. For example, to a construction site located in an urban context, like housing build, it is easier to establish partnership with suppliers than in a road construction site. In vertical building construction is more important to invest in safety than in a simple house construction site.

Despite of this, in Liker (2003) is suggested majority of "Lean companies" are skating at process level. According to this author, to be "lean" is not copy the tools from Toyota in a specific production process. To be "Lean" is develop right principles to its own organization, in order to achieve a high performance of continuous value generating to the clients and society.

Based on that, it is possible to affirm that the use of Lean Tools does not characterize a company as lean, which originated the level zero in the proposed classification or pre-lean level. In this level are companies that reach until 10% of the practices listed on the audit protocol for process principles.

In the level 1, called as initial, is expected an early awareness formation in the top administration about the benefits of lean. This leads to commitment to lean deployment and consequently education to the other levels of the company – assuming a top-down approach. This early awareness is caused by visible and immediate result achieved by companies in its production process. The percentage of practices adopted to stablish this level was 20% of the practices to each category analysed.

It is worth to notice that 20% of evaluation items related with Lean Culture, with 05 items, corresponding a 1 practice, while to Flow, with 26 evaluation items, corresponding a 5. This justify different percentage into y-axes presented in Figure 2.

In the level 2, called as intermediary, is expected to advance up to 40% in all categories, which enables the early signals of a lean awareness in both mid and operational employees (internal clients). From this level of lean implementation, the philosophy permeates all company, although it does not reach the supply chain (external clients), which is expected in the level 3. Some initiatives aimed to buyers and end users (as customization) are under development as lean culture arises.

In the level 3, the lean awareness and practices are sedimented in the companies and to continue improving its performance its is necessary a step forth: integrates the external clients in the supply chain. At this time, is expected accomplishes the roles 1 and 2 of supply chain management in the construction industry, as proposed by Vrijhoef and Koskela (2000), e. g., intensification in development and improvement of specifics supply chains, such as prefabricated concrete elements. Moreover, mass customization and maintenance services to end users are implemented as the lean culture is sedimented. The percentage of practices adopted to stablish this level was 70%.

In the expert category, is expected a prominent lean awareness and the atmosphere of the companies is founded in a Lean culture. As proposed by Liker (2003), in this level, the companies are capables to develop its own lean business model, i.e., new propositions and improvements arises and increase lean mentality itself. It is expected the accomplishment of the roles 3 and 4 of supply chain management (Vrijhoef and Koskela, 2000), as well as

the involvement of clients and users in early stages of the construction project – conception and design of building.

It should be observed that the proposed methodology does not take into account, for the moment, if such management actions are successful. They are taken as successful at this stage to evaluate the actual level of lean implementation. Thus, the efficacy, efficiency and results of this actions are not the object of this evaluation.

The last step of the auditing is the system review. In this step, additional items of evaluation can be proposed by both practitioners and academics. In addition, any evaluation items can be removed, enabling the continuous improvement of the audit protocol. Moreover, as proposed by Franco-Santos *et al*. (2007), an evaluation tool should be flexible and upgradeable not only in terms of items of evaluation, but also in terms of the criterions of evaluation. Thus, the suggested scale can be refined whenever necessary.

CONCLUSIONS

This paper aims to present an audit protocol to evaluates the level of lean implementation. Thus, based on literature review a pilot audit protocol was proposed, which was applied and refined in four cycles into four building companies. Thereinafter, 5 lean experts criticize the protocol, refining it to definitive version.

Then, the final protocol was composed of 4 dimensions, 35 categories, 136 items and 223 examples of verifying evidences. As differential, the presented audit was developed in cooperation with both academic and practitioners, providing a widely and depth understand about lean construction that can helps in its implementation and diagnostic.

Moreover, the final protocol aims to support the lean implementation providing a diagnosis of the current stage and points out directions for a company to improve itself. During the Lean evolution is expected a gradual advance in all dimensions, mainly because the awareness formation pushed by Philosophy sedimentation that will press the others.

As a limitation, it should be observed that the proposed methodology does not take into account, for the moment, if such management actions are successful. Another type of evaluation is necessary for this analysis. Further, the audit protocol can be applied and analysed in different building companies to increases its value in future research.

To conclude, the proposed protocol contributes to better lean construction implementations, suggesting a huge amount of actions organized into TPS dimensions and introducing performance measurement criteria to evaluate them. In the end, through the proposed protocol the lean journey can be tracked by its agents and might prove the actual final purpose of its implementation for both clients and managers, supporting the institutionalization of lean construction in its companies.

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